

Exist-t-il un délai pour le lavage oculaire externe dans le traitement d'un brûlure oculaire par l'ammoniaque? Comparaison de deux solutions de lavage: sérum physiologique et Diphoterine®

[Does a delay exist for external ocular lavage in the treatment of ammonium hydroxide ocular burns? Comparison of two lavage solutions: normal saline and Diphoterine®]

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ABSTRACT

[An Abstract in English is provided in the French original.]

Key Words: Ocular burn, alkalis, ammonium hydroxide, Diphoterine®, ocular lavage

INTRODUCTION

The results of a previous prospective clinical study of ocular base burns in Martinique [1] found that for all severe ocular burns with ammonium hydroxide (Alcali® = 15.3 % ammonium hydroxide; pH = 12.8) reviewed, there was a delay to the initial ocular lavage of greater than 30 minutes. It thus appeared that ocular lavage performed before a delay of several minutes allowed avoiding development of a severe ocular burn. The purpose of our experiments was to find experimental arguments in favor of the existence of a delay and to measure it. This study also compared two available external ocular lavage solutions: normal saline and Diphoterine®.

MATERIALS and METHODS

These experiments were carried out in 18 eyes of New Zealand white rabbits weighing from 2 to 2.2 Kg. The anesthetic methodology and experimental protocol were described in detail in our previous article (M. Gérard et al. Étude expérimentale sur la pénétration intra-oculaire de l'ammoniaque [Experimental study of the intra-ocular penetration of ammonium hydroxide] [French]. J. Fr. Ophtalmol. 1999 (22: 1047-1053) [2]). In summary, under general anesthesia a pH meter probe was placed in the anterior chamber of the rabbit's eye. The pH of the aqueous humor was then recorded before any manipulation, and was confirmed by several stability measurements. Then 0.01 ml of a 15.3% ammonium hydroxide solution was placed on the cornea for 1 minute from the interior of a 7 mm Hoffer optic marker. The choice of this method rendered a valid comparison with our clinical study. In effect, we had a volume/surface area ratio which approached those encountered clinically: 0.02 ml/cm² for a surface area totally immersed, and 0.01 ml/38.5 mm² in our experimental trials.

According to the experimental protocol, blinded lavages were performed either with 250 ml of normal saline or with 250 ml of Diphoterine® following a delay of 1, 3, 5, 10, and 30 minutes following the beginning of placing the ammonium hydroxide on the cornea. Measurements of pH were repeated throughout the experimental period at intervals of 10 seconds for trials of 30 minutes and 5 seconds for the others.

Puncture of the anterior chamber was done at different times. The trial was considered valid if at least 0.1 ml of aqueous humor was retrieved. Measurements of the anterior chamber ammonium hydroxide concentration were then performed. These ammonium hydroxide measurements were done with a Synchron CX® system from Beckman Laboratories (Fullerton, California, USA). This involves a quantitative measurement according to a final point technique. It is an enzymatic analytical method which measures the totality of the ammonium hydroxide present, that is, the concentration of ammonium ion [NH₄⁺] and the concentration of ammonium hydroxide [NH₄OH] itself. This method has analytical limits of 5 to 1,000 Φ mol/l. The near-

totality of measurements made were greater than this concentration. These measurements were obtained by diluting the sample of aqueous humor. A range of samples allowed us to determine, during utilization of dilution, a mean under-estimation of the total ammonium hydroxide concentration measured by this method of 7.7046 mmol/l.

Afterwards, we performed corneal sampling with Vannas scissors in a circular fashion parallel to the limbic area beginning at the catheterized corneal area. The sample was immediately placed in Bouin's solution. Histopathological analysis was also performed in a blinded fashion, that is, before knowing which of the lavage solutions was utilized. The samples were encased in paraffin and slices of 3.5 micrometer thickness were made. Observations were made with an optical microscope after staining with hemalin-phloxine-safran.

For all of the experimental trial durations (1, 3, 5, 10, 30 minutes), there was a control rabbit eye which received an identical burn but which did not benefit from ocular lavage. This control group also had, in a blinded fashion, measurements of anterior chamber ammonium hydroxide concentrations and histopathological analysis of the burned cornea.

The various experimental protocols are summarized in *Table 1*. The results of each experimental trial are displayed in the form of a pH curve as a function of time. The initial portion of the curve displays the pH before any manipulation. The time course of the experimental trial begins with the application of ammonium hydroxide to the eye.

On these curves are shown the beginning (Déb NH₃) and the end (Fin NH₃) of the ammonium hydroxide application, the beginning (Déb lavage) and the end (Fin lavage) of the lavage if one was done, the exact time of the performance of anterior chamber puncture (PCA on the curves), as well as the value of the ammonium hydroxide concentration, expressed in millimoles, measured from this sampling (*fig. 1 to 4*). From this concentration, it is possible to calculate a theoretical pH (pH th. on the curves) by the formula:

$$\text{pH} = 7 + 2 \text{ pKa} + 2 \log [\text{NH}_4\text{OH}]$$

with pKa = 9.2 for ammonium hydroxide. Then, in order to perform comparative studies between curves without and with lavage with Diphoterine® or normal saline, each curve corresponding to a given experimental trial duration is displayed with its homologues on the same graphic. In these graphics, the initial pH is extrapolated to a theoretical pH (0 on the curves), and only variations of pH in relationship with this 0 pH are reported (*fig. 5 and 6*).

RESULTS

For any time of aqueous humor sampling, the values of the concentrations of ammonium hydroxide found in experimental trials with lavage were always less than those in control experimental trials without lavage. On the curves showing only the modifications of pH during lavage, there were no differences between lavage with normal saline and lavage with Diphoterine®. In contrast, the pH curves analyzing the evolution of the pH 7 minutes after Diphoterine® lavage revealed an inflexion of the curve. The pH shown on these curves, moreover, was lower than that shown on corresponding curves for lavage with normal saline (*fig. 6*).

On the histopathological level, epithelial necrosis was noted in all experimental trials,

most often in the form of coagulation necrosis. In contrast, Bowman's and Descemet's membranes were always found to be intact. Except for a discrete edema found during one experimental trial with Diphoterine® lavage 10 minutes after the burn, edema was only noted for certain in experimental trials without lavage or with normal saline lavage (*fig. 8 and 9*).

DISCUSSION

Analysis of our study should be done having a good understanding of its limitations. Ammonium hydroxide is volatile and an exact reproducibility of the number of moles placed on the cornea is thus impossible. Measurements of anterior chamber pH before application of ammonium hydroxide were variable. This variation might be explained by poor calibration of the pH probe. However, as calibration was done before each experiment, this is not likely. In any case, the maximum variation in pH measurements due to poor calibration should be approximately $\nabla 0.5$. It therefore appears that the measurements of relative pH variations remains valid. Similarly, the comparative study of the different pH curves for the same experimental trial duration remains valid when all the curves were re-calculated to the same initial pH (the 0 on our curves) which compared only the variations of pH in relationship with this 0 pH (*fig. 5 and 6*).

The position of the probe in the anterior chamber leads to some variations in the pH measurements, but the only significant variations occurred when the probe was placed behind the iris. Throughout the entire experimental trial, an operator constantly verified the position of the probe, but it must be noted that this control is difficult during lavage.

In fact, the most important limitation involves the method of measuring the ammonium hydroxide concentration in the aqueous humor. The Synchron CX® system allows measurement of total ammonium hydroxide in the aqueous humor; that is, the concentration of ammonium ion (NH_4^+) and ammonium hydroxide itself (NH_4OH). In view of the significant ammonium hydroxide levels which were measured, the measurements could only be done after dilution. However, a range of samples of known concentration allowed placing in evidence that when dilution was utilized, there was a mean 7.7046 mmol/l underestimation of the ammonium hydroxide concentration (see Methods).

A final limitation in the measurement of the ammonium hydroxide concentration is the inclusion of ammonium hydroxide normally present in the aqueous humor from metabolism of amino acids. Reports of measurements of such naturally-occurring ammonium hydroxide were not found in the literature. If such levels were similar to those found in venous blood where ammonium hydroxide is found at a concentration of 18 micromol/l, there would only be 0.0018 micromol in 0.1 ml of aqueous humor, a negligible amount.

Finally, the method of sampling the corneas might induce bias in the histopathological analysis of the corneal burns. In effect, surgical trauma could easily detach the endothelium from the burned cornea, and in this manner the absence of endothelial cells could erroneously be attributed to the burn.

Nevertheless, the overall results appear to be demonstrated from our study. In this fashion, the experimental trials with lavage at 30 minutes (*fig. 7*) correspond with some curves comparable to those of Paterson [4].

Measurements of the ammonium hydroxide concentration at 30 minutes were low, which

suggests a supplemental hypothesis that the interest of external ocular lavage after more than 30 minutes is undoubtedly limited. This experimental hypothesis is in fact concordant with the data from our human clinical study [1] which reported a delay of more than 30 minutes before the initial external ocular lavage in all cases of severe ammonium hydroxide burns.

In contrast, ocular lavage in the first 10 minutes following an ammonium hydroxide burn seems to be beneficial, as all the aqueous humor ammonium hydroxide concentrations were clearly lower (by a factor of 2) than those measured in control experimental trials without lavage.

It should be remembered that this analysis should be tempered by the limitations of the measurement of ammonium hydroxide and the analysis of the pH. The evolution of the pH during lavage with normal saline did not seem to be in variance with the findings seen in the absence of lavage. Paterson [4] previously noted that this fact renewed the interest of lavage 2 to 3 minutes after the burn.

The question is thus as follows: which of these chemical data are the most pertinent for evaluating the efficacy of lavage? Grant [5] affirmed that the ammonium ion is not particularly toxic to the ocular tissues and that only the pH matters. This has obliged us to facilitate a literature search to review the pathophysiology of ocular base chemical burns, and notably the initial limiting action: direct tissue destruction by a chemical agent.

Some time ago, Hughes emphasized that the severity of an ocular burn depends on the concentration, the duration of exposure, and above all the pH of the chemical agent [6,7]. The volume and the individual properties of the chemical agent must be considered. In this manner, the fat solubility of ammonium hydroxide allows it to more easily pass through the epithelial barrier, and its water soluble nature allows it to rapidly pass through the corneal stroma. This explains for the most part its capacity to penetrate and traverse the cornea [4,5,7,8,9]. Finally, it should not be forgotten that the symptoms are only the results of a succession of chemical interactions as demonstrated by Burgher, Blomet and Mathieu [10]. In this fashion, at the simple chemical level, bases cause a single type of reaction: acid-base reactions. It therefore remains to seek acid biological substrates. However, tissue structures possess an infinite quantity of acid-base pairs (for example, amino acids).

The pK scale shows us that the initial chemical reactions which occur are those which deliver the greatest benefit in energetic terms, in accordance with the laws of thermodynamics. These initial reactions are therefore with weak acids. However, during an ocular burn with strong base, this latter is in contact with weak acids: fatty acids are constituents of the lipid membranes of cellular membranes.

Then, after the initial chemical reactions, there are two possibilities. These reactions can lead to total consumption of the base, and the chemical action stops. It is here that idea of the concentration of the offending chemical intervenes. That is to say, these initial reactions do not allow total consumption of the base, and then it continues to react with stronger acids. Other chemical reactions can then occur, and they are only stopped by depletion of the offending chemical or of the biological reactant. However, each new chemical reaction progresses to cause the production of new chemical entities. This introduces a modification of the equilibrium of the chemical entities and in this manner a modification of metabolic levels. The severity of the interaction thus depends on the number of levels affected by the reaction and the quantity of the reactant product modified at each level. At this level a biological fact intervenes: the initial reactions of the base with lipids in the plasma membrane leads to cellular necrosis.

In other words, the base can penetrate into the deep corneal tissues when it comes into

contact, and then initiates other chemical reactions, with stromal collagen, for example. However, the penetration of the base into the interior of the corneal tissue is not only due to this action; it also depends on the classical laws of diffusion: law of osmotic pressure, Fick's law. On the biological level, the lesions induced by bases can also be summarized in this manner. At the epithelial level, bases cause saponification and lysis of cellular membranes which can produce cellular death and in this fashion a clinically apparent ulcer. This necrosis is secondary to a severe increase of the pH [11,12]. The necrosis can also involve the limbic stem cells which assure the regrowth of the corneal epithelium. It is quite evident that the destruction of a significant number of limbic stem cells compromises the long-term healing of the corneal epithelium.

On the clinical level, this cellular destruction is appreciated by limbic ischemia, the extent of which is one of the elements of prognostic classifications of alkaline ocular burns [6,13,14]. Then, if the basic product is not completely consumed by the initial chemical reactions which cause destruction of cellular membranes [10], the chemical can penetrate into the deep layers of the cornea, and especially into the corneal stroma, but only after destroying the basal membrane [15].

The corneal stroma then can serve as the substrate for further chemical reactions with the base. Bases themselves can destroy the stroma, either by necrosis of keratocytes [16], or by cleavage of the peptide fragments of collagen strands [17].

We have already noted that bases can cause denaturation of collagen and glycosaminoglycans, with consequences on corneal transparency [10,18,19]. It is further necessary to cite an indirect effect on this stroma: the ocular burn can rapidly damage the trabeculum causing an increase in the intraocular pressure which is a factor for stromal edema. Finally, as in all cells, the endothelial cells can be necrosed by the reaction of the base on the lipid layer of the cytoplasmic membrane.

It remains therefore to report that the glucose level in the aqueous humor is decreased, which thus diminishes the metabolic potential of the corneal tissues [20]. Similarly, a decrease in the anterior chamber level of ascorbic acid [21,22] compromises the regrowth of stromal collagen. It is in this fashion that the biological consequences of these initial chemical reactions can themselves set in motion other biological perturbations which explain the clinical course and thus the symptomatology of ocular burns with bases.

This review of pathophysiology covers the chain of possible reactions of ammonium hydroxide with numerous weak acids which are tissue constituents. In this group are those with active OH^- ions and the ammonium ion itself. It should equally be remembered that there is a possibility for the cations to react with and denature collagen. Finally, the biological injury due simply to the variation in pH must not be forgotten. However, in this latter case the concentration of OH^- ions plays a role.

Therefore, it is difficult to understand which of these two mechanisms (pH, concentration of ammonium hydroxide) is the most pertinent. Moreover, these two values can only be evaluated by indirect methods which poses a problem, especially when this involves measurements in the aqueous humor, as well as the problems posed by the cornea.

As well, the pH of the aqueous humor is certainly lower than the corneal pH and we do not know how to measure the percentage of ammonium hydroxide, that is to say, the OH^- and NH_4^+ ions which interact chemically at the corneal level. Nevertheless, the present study combined these two factors, from which can be shown the interest of Diphoterine® lavage.

Diphoterine® was more efficacious in comparison to lavage with isotonic normal saline, as was shown in experiments both *in vitro* and *in vivo* [3,23] and in a human clinical study [24] when ocular lavage was done during the initial minutes following the burn.

It is therefore interesting to understand the theoretical efficacy of such a solution. Diphoterine® is an amphoteric solution, hypertonic in comparison with the anterior chamber of the eye. An amphoteric compound is a chemical capable of binding with either a base or an acid without modifying the pH of the milieu. Those such as Diphoterine® are also capable of chelating acids as well as bases, and its hypertonicity creates a movement of water from the hypotonic anterior chamber toward the hypertonic external surface of the cornea, which also causes migration of OH⁻ ions with the water. These OH⁻ ions can then be chelated. This is the simplest mechanism to explain the efficacy of Diphoterine®.

Other mechanisms which are being evaluated to explain the efficacy of Diphoterine® involve its capacity to remove OH⁻ ions from the anterior chamber. In contrast, these explanations allow an understanding that its efficacy could thus only be expressed in a delayed fashion. This is shown when comparing the pH curves made 7 minutes following lavage. These pH curves (*fig. 6*) show an inflexion of the pH curve several seconds to several minutes after lavage with Diphoterine®, while such an inflexion did not occur when lavage was with normal saline. Analysis of pH curve No. 16 (*fig. 4*) is very interesting, as after an inflection of the pH curve, there was another increase in the pH. This can be explained by an insufficient lavage volume. Our analysis is limited by the fact that these comparisons are solely based on single observations and not on mean values from several experimental trials.

Two other limiting factors should be taken into account. The pH measurements were those of the anterior chamber, and not those of the cornea. It is certain that the decrease of the pH in the anterior chamber is clearly more sensitive at the level of the corneal stroma. It is entirely normal that the measurements of the ammonium hydroxide concentrations were identical following lavage with either normal saline or Diphoterine®. Comparisons should take into account the bias introduced by measuring the ammonium hydroxide concentration. Diphoterine® only binds OH⁻ ions, and therefore the total concentration of ammonium hydroxide (NH₄OH + NH₄⁺) is identical. Finally, it must be remarked that 30 minutes after the burn, the pH curve does not develop an inflexion following lavage with either normal saline or Diphoterine® (*fig. 7*).

On the histopathological level, some interesting results were demonstrated in this study. The epithelium rapidly developed necrosis, which even occurred when lavage was done at 1 minute. The corneal epithelium was coagulated in numerous experimental trials, as was also found in humans [2]. In contrast, Bowman's and Descemet's membranes remained uninjured in all experimental trials. This allows the conception that ammonium hydroxide permeates these membranes as it permeates semipermeable membranes (which they are at the biological level), and therefore these membranes do not sustain immediate injury from bases. It is probable that the absence of immediate lesions of these membranes is due to their collagen structure. In effect, it appears that the stromal collagen is only secondarily degraded during alkaline burns.

Grant and Kern [18] have shown that the immediate lesion of the stromal collagen is binding between the cation and the collagen which occurs only when the pH is increased. This binding is partially reversible, and destruction or lysis of the collagen is thus a delayed step in ocular burns with bases, a consequence of the corneal reaction to the burn. It is of note that the

existence of Bowman's membrane is questionable in the rabbit [25].

The presence of stromal edema in these experimental trials without lavage or lavage with normal saline (*fig. 8 and 9*) is in contrast the more remarkable as it was not found when lavage was done with Diphoterine® (with the exception of mild edema in experimental trial No. 18) (*fig. 10*). Stromal edema is a poor prognostic factor. As Kubota and Fagerholm [26] have demonstrated, the extent of this edema is correlated with the extent of the subsequent opaque scarred area, which results in decreased visual acuity. These authors explained this phenomenon by the fact that stromal lacunae formed in this manner by the edema are then colonized by keratocytes. These latter then form a chaotic network of collagen fibers which cause a decrease of corneal transparency. It must moreover be noted that in all cases the experiments described by Kubota and Fagerholm involved lavage with normal saline for 2 minutes following a burn with 1 N sodium hydroxide (NaOH) for 60 seconds.

CONCLUSION

It appears that 30 minutes after an ammonium hydroxide burn, the effect of an external ocular lavage must be only hypothetical, as no inflexion of the pH curve was found. It must also be noted that following this delay, the return to physiological pH was almost attained, which is a supplemental argument. In contrast, it seems that the interest of ocular lavage with Diphoterine® in comparison to ocular lavage with normal saline, during the first 10 minutes after an ocular burn with ammonium hydroxide, can be established on histopathological grounds: the absence of stromal edema following lavage with Diphoterine® and its presence following lavage with normal saline and on biological grounds: the inflexion of the pH curve following Diphoterine® lavage.

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REFERENCES

(See French original.)

TABLE I: SUMMARY OF EXPERIMENTAL PROTOCOLS

* ACP = Anterior Chamber Puncture for ammonium hydroxide concentration measurement in

the aqueous humor

Eye Burned with NH ₃ for 1 minute - No Lavage	Eye Burned with NH ₃ for 1 minute; then lavaged with normal saline at t = ____ minute(s); immediate ACP*	Eye Burned with NH ₃ for 1 minute; then lavaged with normal saline at t = ____ minute(s); ACP 7 minutes following completion of lavage	Eye Burned with NH ₃ for 1 minute; then lavaged with Diphoterine® at t = ____ minute(s); ACP 7 minutes following completion of lavage	Eye Burned with NH ₃ for 1 minute; then lavaged with Diphoterine® at t = ____ minute(s); immediate ACP
ACP for ammonium hydroxide measurement at 1 minute	t = 1 minute	t = 1 minute	t = 1 minute	t = 1 minute
ACP for ammonium hydroxide measurement at 3 minutes	t = 3 minutes	t = 3 minutes	t = 3 minutes	t = 3 minutes
ACP for ammonium hydroxide measurement at 5 minutes	t = 5 minutes	t = 5 minutes	t = 5 minutes	t = 5 minutes
ACP for ammonium hydroxide measurement at 10 minutes	t = 10 minutes	t = 10 minutes	t = 10 minutes	t = 10 minutes
ACP for ammonium hydroxide measurement at 30 minutes		t = 30 minutes	t = 30 minutes	

FIGURE LEGENDS

Figure 1:

Courbe d'évolution du pH = pH evolution curve
t = 3 min, lavage au sérum physiologique, PCA immédiate =
t = 3 minutes, lavage with normal saline, immediate ACP
Temps (mn) = Time (minutes)
Déb NH3 = beginning of ammonium hydroxide exposure
Fin NH3 = end of ammonium hydroxide exposure
Déb lavage = beginning of lavage
Fin lavage = end of lavage
PCA = anterior chamber puncture (ACP)
pH th. = theoretical pH

Figure 2:

Courbe d'évolution du pH = pH evolution curve
t = 3 min, lavage à la diphoterine, PCA immédiate =
t = 3 minutes, lavage with Diphoterine®, immediate ACP
Temps (mn) = Time (minutes)
Déb NH3 = beginning of ammonium hydroxide exposure
Fin NH3 = end of ammonium hydroxide exposure
Déb lavage = beginning of lavage
Fin lavage = end of lavage
PCA = anterior chamber puncture (ACP)
pH th. = theoretical pH

Figure 3:

Courbe d'évolution du pH = pH evolution curve
t = 3 min, lavage au sérum physiologique, PCA 7 min =
t = 3 minutes, lavage with normal saline, ACP 7 minutes
Temps (mn) = Time (minutes)
Déb NH3 = beginning of ammonium hydroxide exposure
Fin NH3 = end of ammonium hydroxide exposure
Déb lavage = beginning of lavage
Fin lavage = end of lavage
PCA = anterior chamber puncture (ACP)
pH th. = theoretical pH

Figure 4:

Courbe d'évolution du pH = pH evolution curve
t = 3 min, lavage à la diphoterine, PCA 7 min =
t = 3 minutes, lavage with Diphoterine®, ACP 7 minutes
Temps (mn) = Time (minutes)
Déb NH3 = beginning of ammonium hydroxide exposure

Fin NH₃ = end of ammonium hydroxide exposure

Déb lavage = beginning of lavage

Fin lavage = end of lavage

PCA = anterior chamber puncture (ACP)

pH th. = theoretical pH

Figure 5:

Graphique comparatif des courbes d'évolution du pH. Expérimentation lavage à 3 min, PCA immédiate. Courbes avec lavage à la Diphoterine® et au sérum physiologique superposables. = Comparative graphic of pH evolution curves. Trial with lavage at 3 minutes, immediate ACP. Curves for lavage with Diphoterine® and with normal saline superimposed.

PCA = Anterior chamber puncture (ACP)

Evolution du pH = pH evolution

Temps (mn) = Time (minutes)

[filled circles] Courbe n° 2: Evolution du pH, t = 3 min, sans lavage =

Curve No. 2: pH evolution, t = 3 minutes, no lavage

[filled squares] Courbe n° 7: Evolution du pH, t = 3 min, lavage au sérum physiologique, PCA immédiate = Curve No. 7: pH evolution, t = 3 minutes, lavage with normal saline, immediate ACP

[filled squares] Courbe n° 21: Evolution du pH, t = 3 min, lavage à la diphoterine, PCA immédiate = Curve No. 21, pH evolution, t = 3 minutes, lavage with Diphoterine®, immediate ACP

Figure 6:

Graphique comparatif des courbes d'évolution du pH. Expérimentation lavage à 3 min, PCA après 7 min. Inflexion de la courbe pH après 7 min. Absence d'inflexion de la courbe pH après lavage au sérum physiologique = Comparative graphic of pH evolution curves. Trial with lavage at 3 minutes, ACP after 7 minutes. Inflexion of the pH curve after lavage with Diphoterine®. Absence of inflexion after lavage with normal saline.

PCA = Anterior chamber puncture (ACP)

Evolution du pH = pH evolution

Temps (mn) = Time (minutes)

[filled circles] Courbe n° 2: Evolution du pH, t = 3 min, sans lavage =

Curve No. 2: pH evolution, t = 3 minutes, no lavage

[filled squares] Courbe n° 11 Evolution du pH, t = 3 min, lavage au sérum physiologique, PCA 7 min = Curve No. 11: pH evolution, t = 3 minutes, lavage with normal saline, ACP 7 min

[filled squares] Courbe n° 16: Evolution du pH, t = 3 min, lavage à la diphoterine, PCA 7 min = Curve No. 16, pH evolution, t = 3 minutes, lavage with Diphoterine®, ACP 7 minutes

Figure 7:

Graphique comparatif des courbes d'évolution du pH. Expérimentation lavage à 30 min, PCA après 7 min. Courbes avec lavage à la Diphoterine® et au sérum physiologique superposables avec quasi retour au pH physiologique. Taux d'ammoniaque intracaméculaire faible = Comparative graphic of pH evolution curves. Trial with lavage at 30 minutes, ACP after 7 minutes. Curves for lavage with Diphoterine® and with normal saline superimposed with near-return to a physiological pH. Low levels of anterior chamber ammonium hydroxide.

PCA = Anterior chamber puncture (ACP)

Evolution du pH = pH evolution

Temps (mn) = Time (minutes)

[filled circles] Courbe n° 5: Evolution du pH, t = 30 min, sans lavage =

Curve No. 5: pH evolution, t = 30 minutes, no lavage

[filled squares] Courbe n° 14 Evolution du pH, t = 30 min, lavage au sérum

physiologique, PCA 7 min = Curve No. 14: pH evolution, t = 30 minutes, lavage with normal saline, ACP 7 min

[filled squares] Courbe n° 19: Evolution du pH, t = 30 min, lavage à la diphoterine, PCA

7 min = Curve No. 19, pH evolution, t = 30 minutes, lavage with Diphoterine®, ACP 7 minutes

Figure 8:

Histopathological analysis of a cornea burned with ammonium hydroxide and lavaged after 3 minutes with normal saline: Coagulated epithelium; edematous stroma.

Figure 9:

Histopathological analysis of a cornea burned with ammonium hydroxide and not lavaged; removed for examination after 5 minutes: stromal edema, normal Descemet's membrane, absent endothelial cells.

Figure 10:

Histopathological analysis of a cornea burned with ammonium hydroxide and lavaged after 3 minutes with Diphoterine®: vacuolized and coagulated epithelium, normal stroma.